AD NO. ______________________________
DTC PROJECT NO. 8-CO-160-UXO-016
REPORT NO. ATC-9329

SHALLOW WATER

UXO TECHNOLOGY DEMONSTRATION SITE

SCORING RECORD NO. 5

SITE LOCATION:
U.S. ARMY ABERDEEN PROVING GROUND

DEMONSTRATOR:
NAEVA GEOPHYSICS, INC.
P.O. BOX 7325
CHARLOTTESVILLE, VA 22906

TECHNOLOGY TYPE/PLATFORM
EM61 MKII

PREPARED BY:
U.S. ARMY ABERDEEN TEST CENTER
ABERDEEN PROVING GROUND, MD 21005-5059

APRIL 2008

Prepared for:
U.S. ARMY ENVIRONMENTAL COMMAND
ABERDEEN PROVING GROUND, MD 21010-5401

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ABERDEEN PROVING GROUND, MD 21005-5055

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This report documents the efforts of NAEVA/XTECH to detect and discriminate inert unexploded ordnance (UXO) using an EM61 MKII. Testing was conducted at ATC, Standardized Shallow Water UXO Technology Demonstration Site. A description of the tested system and an estimate of survey costs along with the analysis of the system performance are provided.

15. SUBJECT TERMS

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This document corrects discrepancies between the data published in Scoring Record No.5 dated January 2007 and the actual test results. Affected sections are the open water detection and discrimination tables and associated ROC curves.

14. ABSTRACT

This report documents the efforts of NAEVA/XTECH to detect and discriminate inert unexploded ordnance (UXO) using an EM61 MKII. Testing was conducted at ATC, Standardized Shallow Water UXO Technology Demonstration Site. A description of the tested system and an estimate of survey costs along with the analysis of the system performance are provided.

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SECTION 1. GENERAL INFORMATION

1.1 BACKGROUND

Technologies under development for the detection and discrimination of munitions and explosives of concern (MEC), i.e., unexploded ordnance (UXO) and discarded military munitions (DMM), require testing so their performance can be characterized. To that end, the U.S. Army Aberdeen Test Center (ATC) located at Aberdeen Proving Ground (APG), Maryland, has developed a Standardized Shallow Water Test Site. This site provides a controlled environment containing varying water depths, multiple types of ordnance and clutter items, as well as navigational and detection challenges. Testing at this site is independently administered and analyzed by the government for the purposes of characterizing technologies, tracking performance during system development, and comparing the performance and costs of different systems.

The Standardized UXO Technology Demonstration Site Program is a multiagency program spearheaded by the U.S. Army Environmental Command (USAEC). ATC and the U.S. Army Corps of Engineers Engineering, Research and Development Center (ERDC) provide programmatic support. The Environmental Security Technology Certification Program (ESTCP), the Strategic Environmental Research and Development Program (SERDP), and the Army Environmental Quality Technology Program (EQT) provided funding and support for this program.

1.2 OBJECTIVE

The objective of the Shallow Water Standardized UXO Technology Demonstration Site is to evaluate the detection and discrimination capabilities of existing and emerging technologies and systems in a shallow water environment. Specifically:

a. To determine the demonstrator’s ability to survey a shallow water area, analyze the survey data, and provide a prioritized “Target List” with associated confidence levels in a timely manner.

b. To determine both the detection and discrimination effectiveness under realistic scenarios that varies ordnance, clutter, and bathymetric conditions.

c. To determine cost, time, and manpower requirements needed to operate the technology.

1.3 CRITERIA

The scoring criteria specified in the Environmental Quality Technology - Operational Requirements Document (EQT-ORD) (app D, ref 1) for: A(1.6.a): UXO Screening, Detection and Discrimination document are presented in Table 1-1. Very little information was available on the capabilities of shallow water detection systems when these criteria were developed. However, they were used in the design of the test site, and the five metrics were used to measure system performance in this report.

TABLE 1-1. SCORING CRITERIA

Metric	Threshold	Objective
Detection	80% ordnance items buried to 1 foot and under 8 feet (2.4 m) of water at a standardized site detected	95% ordnance items buried to 4 feet and under 8 feet (2.4 m) of water at a standardized site detected
Discrimination	Rejection rate of 50% of emplaced non-UXO clutter at a standardized site with a maximum false negative rate of 10%	Rejection rate of 90% of emplaced non-UXO clutter at a standardized site with a maximum false negative rate of 0.5%
Reacquisition	Reacquire within 1 meter	Reacquire within 0.5 meter
Cost rate	$4000 per acre	$2000 per acre
Production rate	5 acres per day	50 acres per day

The ATC shallow water site is designed to evaluate the threshold detection level of a range of ordnance at the 1-foot + 8-foot requirement. Limited information is available at the objective detection level. All other measured results in this test were evaluated against both criteria levels.

1.4 APG SHALLOW WATER SITE INFORMATION

1.4.1 Location

The Aberdeen Area of APG is located in the northeast portion of Maryland on the western shore of the Chesapeake Bay in Harford County. The Shallow Water Test Site is located within a controlled range area of APG.

1.4.2 Soil Type

The area chosen for the shallow water test site was known as Cell No. 3 in a dredge-spoil field. The cell bottom is composed primarily of sediment removed from the Bush River. This is a freshwater site.

1.4.3 Test Areas

a. The test site contains five areas: calibration grid, blind test grid, littoral, open water, and deeper water. Additional detail on each area is presented in Table 1-2. A schematic of the calibration lanes is shown in Figure 1.

TABLE 1-2.   TEST AREAS

Area	Description
Calibration grid	The calibration area contains 15 projectiles, 3 each 40, 60, 81, 105, and 155 mm. One of each projectile type is buried at the projectile diameter to depth ratio shown in Figure 1. This area is designed to provide the user with a sensor library of detection responses for the emplaced targets and an understanding of their resistivity prior to entering the blind test fields. Two “clutter-cloud” target scenarios have been constructed adjacent to this area (fig. 1).
Blind grid	The blind grid contains 644 detection opportunities. Each grid cell is $2 \times 2\ m^2$. At the center of each cell is either an ordnance item, clutter, or nothing. Surrounding the blind grid on three sides are 3.6-kg (8-lb) shot puts, buried 0.3 meters deep in the sediment. The shot puts can be used as a navigational/Global Positioning System (GPS) check. The GPS coordinates for the center of each grid and the shot put locations are provided to the vendor prior to testing.
Littoral	This is a sloping area on one side of the pond with vegetation growing into the waterline. Water depth ranges from 0.3 to 1.8 meters. It contains a variety of navigational and detection challenges.
Open water	The open water scenario contains a variety of navigational, detection, and discrimination challenges. Water depth varies from 1.8 to 3.4 meters.
Deeper water	The water depth in this area varies between 3.4 and 4.3 meters.

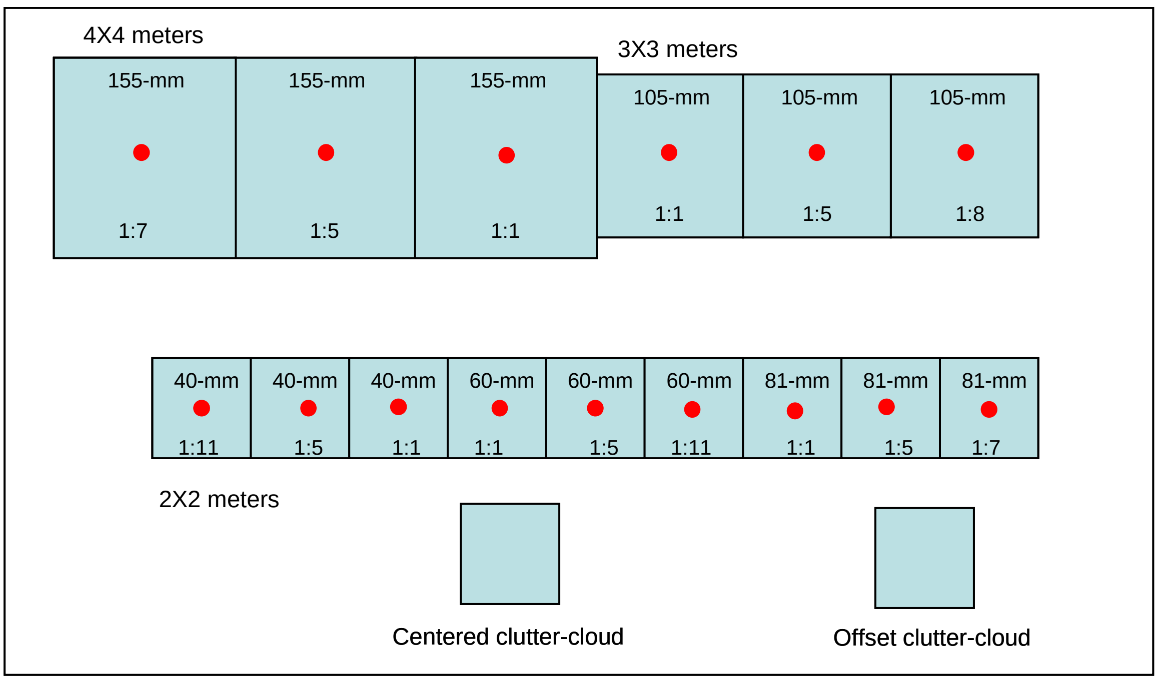

Figure 1.   Schematic of the calibration grid.

b. The water depth at this facility during testing is maintained such that the calibration and blind grid areas meet the 2.4-meter (8-ft) detection criterion specified in section 1.3. The test site is approximately 2.8 hectares (6.9 acres) in size.

1.5 GROUND TRUTH TARGETS

The ground truth is composed of both inert ordnance and clutter items. The inert ordnance items are listed in Table 1-3. All items were located in storage sites at APG. The items have not been fired or degaussed.

Clutter items fit into one of three categories: ferrous, nonferrous, and mixed metals. The ferrous and nonferrous items have been further divided into three weight zones as presented in Table 1-4, and distributed throughout all test areas. Most of this clutter is composed of ordnance components; however, industrial scrap metal and cultural items are present as well. The mixed-metals clutter is composed of scrap ordnance items or fragments that have both a ferrous and nonferrous component and could reasonably be encountered in a range area. The mixed-metals clutter was placed in the open water area only.

TABLE 1-3. INERT ORDNANCE TARGETS

Description	**Length, mm**	**Diameter, mm**	**Aspect Ratio, W/L**	**Weight, g**
40-mm L70 projectile	208	40	0.1923	965
60-mm mortar M49A2	185	60	0.3243	975
81-mm mortar M374	528	81	0.1534	3969
81-mm mortar M821	510	81	0.1588	3338
105-mm projectile M1	445	105	0.2360	13834
155-mm M107 projectile	684	155	0.2266	41731
8-in. M104/106	856	203	0.2371	89811

TABLE 1-4. CLUTTER WEIGHT RANGES

Clutter Type	**Weight Range in Grams**		
	Small	**Medium**	**Large**
Ferrous	10 to 510	511 to 2200	> 2201
Nonferrous	10 to 270	275 to 800	> 801

SECTION 2. SYSTEM UNDER TEST

2.1 DEMONSTRATOR INFORMATION

NAEVA provided the information in sections 2.1 through 2.6 as part of their Broad Agency Announcement (BAA) proposal (app D, ref 2). Section 2.8 contains ATC's comments on the demonstrated system.

Note: The provided demonstrator information has been edited to comply with government report guidelines.

2.2 SYSTEM DESCRIPTION

a. For this demonstration, NAEVA proposed to work with XTECH to deploy the multisensor underwater system using Geonics EM61 MKII (underwater coils) electromagnetic (EM) metal detectors. The system was relatively lightweight, requiring a small aluminum boat for towing. This configuration should have allowed the team to achieve full coverage of the site, even in relatively shallow areas. Accurate data positioning was achieved using a real-time kinematic GPS.

b. The deployed system (fig. 2) consisted of two underwater coils mounted side by side on a specially designed acrylonitrile-butadiene-styrene (ABS) sled. A GPS mast, centered over the two coils, was attached directly to the sled and allowed accurate positional tracking of the sensor data. The unit was towed by a 14-foot aluminum boat powered by an outboard motor with a specialized prop. The custom fabrication and rigging designed for the system allowed excellent boat control and maneuverability while towing. During data collection, the coil assembly glided across the bottom on the smooth plastic underbelly of the sled.

Figure 2. XTECH sled with EM61 coils.

2.3 DEMONSTRATOR'S POC AND ADDRESS

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2.4 DEMONSTRATOR'S SITE SURVEY METHOD

NAEVA intended to fully map the Shallow Water Standardized Test Site, using XTECH's dual-sensor underwater detection system. Mapping activities included the calibration lanes, blind grid area, and open water sites, including both the deep water and littoral zones (fig. 3). All field areas were surveyed in the prescribed order in a single orientation (e.g., north-south, east-west). If time permitted, NAEVA could elect to remap certain portions or the entire site in a second orientation to enhance the data quality.

Figure 3. XTECH sled in the open water area.

2.5 DEMONSTRATOR'S QC AND QA

a. For purposes of this proposal, QA is defined as the procedures to be employed during the demonstration.

b. All geophysical data were collected with real-time GPS data positioning from an antenna mounted above the two coils. EM data were collected at a rate of 10 readings per second, which equates to more than one reading per foot. GPS locations were logged at a rate of one reading per second. To maintain straight-line profiling and to minimize the occurrence of gaps within the data, real-time sensor-tracking software was used. The Trimble Ag170 navigation system includes a light-up display mounted in the boat that indicates the direction and degree of correction necessary to maintain a straight path. Positional data supplied for the calibration lanes and blind grid area are overlaid on the track map to ensure that full site coverage has been achieved. Although the GPS has a listed accuracy of 3 cm, the expected accuracy of resultant target selections was signified by a circle with a 1-foot radius around each target.

c. To establish confidence in the data reliability, tests were conducted in a systematic manner throughout the duration of the fieldwork. Various types of QC data were generated before, during, and after all data collection sessions.

d. Daily: A location was identified that had no subsurface metal and was designated as a calibration point. Readings were collected in a stationary position over the calibration point to ensure that a stable and repeatable response was exhibited. This test was performed twice daily to establish that the instrument was functioning properly, as indicated by a stable and repeatable response.

e. A line containing at least one seeded item was identified within the calibration lanes that served as a standard response and latency check. At the start and end of each field day, two lines were collected bidirectionally across the item using, as close as possible, the same line path. The data were then reviewed for consistent response and positioning and to determine an appropriate latency correction.

f. During data collection: On completion of the original collection of a data set, approximately 5% of the line footage for each surveyed area was re-collected as a check of instrument repeatability and positioning. The repeat lines were saved to separate files and used to create profiles that provided a direct comparison with the original data. Each profile was evaluated for repeatability in both instrument response and data positioning.

2.6 DATA PROCESSING DESCRIPTION

a. The geophysical data were temporarily stored in the system's integrated logger during data collection and then downloaded into a laptop computer for on-site review and editing. Using Geosoft's Oasis Montaj software, a track plot of the instrument's GPS positions was created to ensure that adequate data coverage had been achieved. Preliminary contour maps were created for field review of each survey area. Once in-field processing and review were completed, the data were electronically transferred to NAEVA's Virginia office for analysis/target selection.

b. Geosoft's Oasis Montaj UXO software package was used to post process and contour the raw data and to identify potential UXO targets. The program identifies peak amplitude responses of the frequency associated with, but not limited to, UXO items. Anomalies may have generated multiple target designations depending on individual signature characteristics.

c. Geophysical data processing included the following:

(1) Instrument drift correction (leveling).

(2) Lag correction.

(3) Digital filtering and enhancement (if necessary).

(4) Gridding of data.

(5) Selection of all anomalies.

(6) Selection of targets for intrusive characterization.

(7) Preparation of geophysical and target maps.

c. Final target lists for the three scenarios will be prepared separately in the specified formats and then submitted for scoring.

2.7 DEMONSTRATOR'S SITE PERSONNEL

NAEVA Project Geophysicists:	Mr. Alexander Z. Kostera Mr. Leif Riddervold
XTECH Data Acquisition Specialists:	Mr. Vik Banerjee Mr. Mark J. Howard

2.8 ATC'S SURVEY COMMENTS

a. Several design shortcomings of this system affect both safety and performance. The bottom of the sled is a rectangular platform constructed with ABS pipe. Three pipes rode on the pond bottom parallel to the direction of boat travel; two were dragged perpendicular to the direction of travel (beneath the EM coils). At the front of the sled, the parallel pipes were angled upward with a perpendicular support (fig. 2 and 4). The configuration permitted objects to enter and then become trapped in the front of the sled.

Figure 4. Side view of sled.

The vertical component of this sled was approximately 10 feet high and was also constructed of ABS pipe (fig. 2). An additional 4-foot pipe was added when the system surveyed the deeper water area of the site (white pipe visible in fig. 3). Cement-filled pipes, placed inside the sled runners, served two purposes: to ensure that the sled remained on the bottom and to lower the center of gravity (fig. 5).

Figure 5. Cement ballast.

This design did not work at this test site. The platform was unstable, particularly when turning. A second person in a kayak was occasionally needed to reorient the sled in an upright position (fig. 6).

Figure 6. Reorienting the survey sled.

The amount of ballast placed in the ABS pipes along with the sled design also dislodged an undetermined number of test items that had been either emplaced on the pond bottom or pressed into the sediment to be flush with the bottom. The first confirmation that this was happening occurred during the post-survey processing done by NAEVA at the test site (fig. 7). An ATC geodetic/dive team attempted to locate 15 randomly selected ground truth targets after XTECH's survey (fig. 8). All 15 were moved from their locations. Divers reported that they could see where some items had been, along with the marks left by the sled.

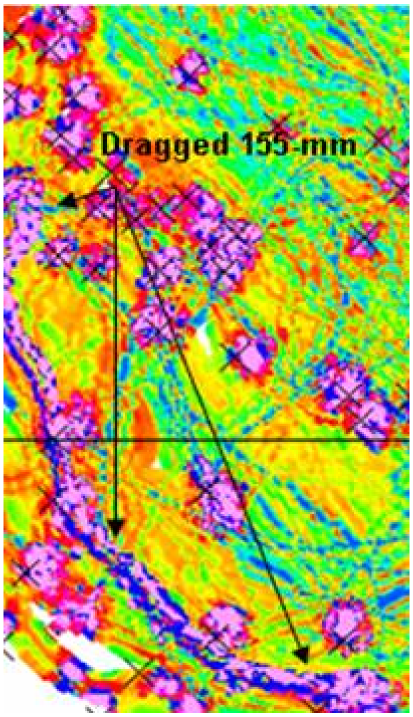

Figure 7. Dragged projectile.

Figure 8. Checking target locations.

At an actual MEC remediation site, this type of system would increase the chances of an explosive event. A 2-meter water depth and the length of the towrope would provide a limited level of personal protection, depending on the explosive item, but equipment replacement could be costly. During this evaluation, moving the ground truth items could have distorted the EM signatures, increased the percentage of false positives or background alarm calls in the scoring process and possibly degraded the performance evaluation of this system.

A rope that was looped around the bow of the boat and attached at two points on the sled pulled the sled. Poles mounted on the stern of the boat that extended below the waterline prevented the rope from being caught by the outboard motor propeller. This arrangement worked well when the sled was pulled in a straight line and when the boat could make wide turns. However, when there was no tension on the towrope and the boat was maneuvering, the rope could get into the propeller. This towing system did not work well at this test site.

SECTION 3. SURVEY COST ANALYSIS

3.1 DATES OF SURVEY

The NAEVA/XTECH EM system was tested from 3 through 14 April 2006.

3.2 SITE CONDITIONS

3.2.1 Atmospheric Conditions

An ATC weather station located adjacent to the test site recorded the average temperature and precipitation on an hourly basis for each day of operation. The temperatures listed in Table 3-1 represent the average temperature from 0700 through 1700. The hourly weather logs used to generate this summary are provided in Appendix A.

3.2.2 Water Conditions

Water conditions were monitored using a TIDALITE IV Portable Tide Gauge System©. Data recorded included water depth and temperature, significant wave height based on the average 1/3 wave height seen over the test period using the Draper/Tucker analysis method, and the full-wave frequency calculated by full-wave mean crossing detection. The values displayed in Table 3-1 were averaged from 0700 through 1700.

TABLE 3-1. SITE CONDITION SUMMARY

Date, 06	Air Temperature, °C	Wind, km/h	Water Temperature, °C	Water Depth, m[a]	Significant Wave Height, m	Wave Frequency, Hz
3 Apr	13.1	7.0	10	-0.1	Lost	Lost
4 Apr	10.2	25.0	10	-0.1	Lost	Lost
5 Apr	6.5	22.1	10	-0.1	Lost	Lost
6 Apr	10.7	11.1	10	-0.1	Lost	Lost
7 Apr	12.5	12.7	10	-0.1	Lost	Lost
10 Apr	11.4	8.4	10	-0.2	Lost	Lost
11 Apr	13.9	12.0	10	-0.2	Lost	Lost
12 Apr	16.0	15.8	10	-0.2	Lost	Lost
13 Apr	19.7	10.7	10	-0.2	Lost	Lost
14 Apr	16.7	7.2	11	-0.2	Lost	Lost

[a]Variance between the required 2.4-meter test depth and actual test conditions.
Lost = instrumentation malfunction.

3.3 SURVEY ACTIVITIES

The information contained in this section provides an estimate of the time needed and costs associated with surveying an area with this demonstrator's system. This includes data on equipment setup and calibration, site survey and any resurvey time, and downtime due to system malfunctions and maintenance requirements.

3.3.1 Survey Times

a. A government representative monitored and recorded all on-site activities, which were grouped into one of 11 categories. The first eight categories were chargeable to the system while the last three were not. Categorizing these activities provided insight into the technical and logistical aspects of the system. The times recorded in each category were then matched with the number of demonstrator personnel, assigned skill levels, and a consistent (across-vendor) salary to produce an estimate of the survey costs.

(1) Initial setup/mobilization. Started at the time the demonstrator's equipment arrived at the survey site and stopped when the system was ready to acquire data.

(2) Daily setup/close-up. Monitored time spent mounting and dismounting the equipment each day.

(3) Instrument calibration. Recorded the amount of time used for daily quality assurance checks (e.g., sensors, GPS data, survey data quality).

(4) Data collection. Time spent surveying the test area.

(5) Downtime (nonsurvey time) for equipment/data checks. Covered time spent troubleshooting equipment or verifying survey tracks.

(6) Downtime (nonsurvey time) for equipment failure. Examples include replacing damaged cables, lost communication with base station, and any other failure that prevented surveying. Some weather-related failures fall into this category, for example, light-emitting diode (LED) displays darkened by the sun, wind creating waves too high to permit surveying, etc.

(7) Downtime (nonsurvey time) for maintenance. Battery replacement and memory downloads are typical examples.

(8) Demobilization. Commenced once the demonstrator completed the survey and concluded the final on-site check of the test data and ended when the equipment and personnel were ready to leave the site.

(9) Nonchargeable downtime for breaks and lunch. The demonstrator's company policy set this standard.

(10) Nonchargeable downtime for weather-related causes (i.e., lightning, high wet-bulb heat index, and similar events).

(11) Nonchargeable downtime due to ATC range operating requirements. Danger zone conflicts, lack of support personnel, equipment, or other ATC-caused delays.

b. Appendix B contains the daily log sheets. Table 3-2 summarizes that information to provide insight into the operational, maintenance, and logistic aspects of the system.

TABLE 3-2. TIME ON-SITE

Date, 06	**3 Apr**	**4 Apr**	**5 Apr**	**6 Apr**	**7 Apr**	**10 Apr**	**11 Apr**	**12 Apr**	**13 Apr**	**14 Apr**	**Activity Totals, hr**
Activity (daily times recorded in minutes)											
Initial setup	325	205	-	-	-	-	-	-	-	-	8.8
Daily setup/ close-up	-	30	65	60	80	70	70	100	20	30	8.8
Instrument calibration	-	55	10	10	-	5	60	5	5	15	2.8
Data collection	-	40	-	220	-	260	320	180	275	155	24.2
Equipment/ data checks	-	-	-	-	-	-	-	-	-	-	0.0
Equipment failure	-	40	-	85	-	135	30	240	210	-	12.3
Maintenance	-	-	-	-	-	-	-	-	-	-	0.0
Demobilize	-	-	-	-	-	-	-	-	-	175	2.9
Breaks/ lunch	30	-	-	60	-	30	60	15	-	-	3.3
Weather-related	80	80	345	-	340	-	-	-	-	-	14.1
ATC downtime	15	-	-	-	-	-	-	-	-	-	0.3
Daily total, hr	7.5	7.5	6.8	7.3	7.0	7.2	9.0	9.0	8.5	6.3	

Note: Task times are rounded to 5-minute increments.

3.3.2 On-Site Data Collection Costs

The times associated with the 11 activities have been grouped into the three basic components of the evaluation: initial setup, site survey, and pack-up (demobilization). Note that site survey time includes daily setup/stop time, data collection, breaks/lunch, downtime for equipment/data checks or maintenance, downtime due to failure, and downtime due to weather. This combines the actual survey cost with the demonstrator's associated on-site overhead costs.

A standardized estimate for labor costs associated with this effort was then calculated using the following job categories: supervisor ($95.00/hr), data analyst ($57.00/hr), and site support ($28.50/hr). The estimated costs are presented in Table 3-3.

TABLE 3-3. CALCULATED SURVEY COSTS

	No. of Persons	Hourly Wage	Hours	Cost
Initial Setup				
Supervisor	1	$95.00	8.8	$836.00
Data analyst	1	$57.00	8.8	$501.60
Site support	2	$28.50	8.8	$501.60
Subtotal				**$1,839.20**
Site Survey				
Supervisor	1	$95.00	48.1	$4,569.50
Data analyst	1	$57.00	48.1	$2,741.70
Site support	2	$28.50	48.1	$2,741.70
Subtotal				**$10,052.90**
Demobilization				
Supervisor	1	$95.00	2.9	$275.50
Data analyst	1	$57.00	2.9	$165.30
Site support	2	$28.50	2.9	$165.30
Subtotal				**$606.10**
Total on-site costs				**$12,498.20**

3.4 COST ANALYSIS

The data collection process described above provided an on-site cost guide to compare the performance of this vendor with any other that has demonstrated at the shallow water site. It is not a true indicator of survey costs. Many other expenses have not been included, such as travel costs, per diem, off-site data processing and analysis, company overhead, and profit.

Calculating the area surveyed was done by plotting the raw GPS coordinates and then combining the sensor swath (line spacing and associated overlap).

To determine the number of acres surveyed per day, the total number of hours spent at the test site (table 3-2) was divided by 8 (converts to 8-hr days). The number of acres was then divided by the number of 8-hour days. The cost per acre was determined by dividing the total survey costs (table 3-3) by the same number of acres. This information is summarized in Table 3-4.

TABLE 3-4. SURVEY COSTS

Area surveyed (acre[a])	3.7
Time on-site (8-hr days)	7.5
Calculated survey cost (U.S. dollars)	$12,489
Acres per day	0.49
Cost per acre	$3,378

[a]Acre = 4047 m^2.

Table 3-5 presents a comparison of Tetra Tech's survey costs with the EQT-ORD criteria.

TABLE 3-5. TEST RESULTS - CRITERIA COMPARISON

Metric	Threshold	Objective	NAEVA/XTECH
Cost rate	$4000 per acre	$2000 per acre	$3378
Production rate	5 acres per day	50 acres per day	0.49

SECTION 4. TECHNICAL PERFORMANCE RESULTS

4.1 AREA SURVEYED

4.1.1 Calculated Area

a. Both the test and scoring methodologies required the demonstrator to survey 100 percent of each of the four test areas (blind grid, open water, littoral, and deeper water). Scoring a partially surveyed area alters the ordnance and clutter sample sizes, and test area boundaries, and decreases the statistical confidence in the performance statements made for that area. Allowing partial scoring decreases the validity of performance comparisons made between multiple test areas for a single demonstrator and comparisons made between multiple demonstrators for a single test area.

b. Realizing that some systems may not be able to survey 100 percent of a given test area, a ranking system was established. The percent coverage for a given test area is determined by first plotting the raw GPS coordinates combined with the sensor swath (line spacing and associated overlap), calculating the area surveyed, and then comparing the surveyed area with the total test area.

$$\frac{\text{Section Surveyed}}{\text{Test Area Size}} \times 100 = \% \text{ Surveyed}$$

c. The demonstrator's system is always scored against the complete ground truth for a given test area regardless of the percentage covered.

4.1.2 Area Assessment

The ranking system and survey results are presented in Table 4-1.

TABLE 4-1. M882 SURVEY RANKING SYSTEM AND RESULTS

Ranking System		Survey Results		
% Area Covered	**Ranking**	**Test Area**	**% Area Covered**	**Data Use**
95 to 100	Met	Blind grid	98	Direct comparison between systems and areas.
90 to 94	Generally met			Comparison between systems and areas. A small negative bias is contained in the reported numbers (bias not quantified in this report).
50 to 89	Partially met	Open water	84	Reported, not compared between systems or areas. A large negative bias is contained in the reported numbers (bias not quantified in this report).
		Deeper water	65	
0 to 49	Not met	Littoral	10	Not scored/not reported.

4.2 SYSTEM SCORING PROCEDURES

a. The scoring entities used in this program were predicated on knowing the composition and location of every detectable item in an area. The deeper water area is the one exception. Ground truth targets were placed in this area without a pre-survey and clearing operation. Therefore, only the system's probability of detection (P_d) was evaluated in this area.

b. The best indicator of survey performance is the blind grid. This area provides a statically valid, controlled environment in which the demonstrator must provide a response (ordnance, clutter, or blank) at each of the 644 locations. Comparison of the response and discrimination lists to the ground truth in this area both determines the range of ordnance the system can reliably detect and establishes the baseline to which system performance in all other test areas is measured.

c. The scoring terms and definitions, along with an explanation of the receiver operating characteristic (ROC) curve development and the chi-square analysis used in this report, are provided in Appendix C.

d. Demonstrator performance was scored in two stages: response and discrimination.

e. Response stage scoring evaluates the ability of the demonstrator's system to detect emplaced ground truth targets without regard to discriminating ordnance from clutter. In this stage, the GPS locations and signal strengths of all anomalies the demonstrator deemed sufficient for further investigation and/or processing are reported. This list was generated with minimal processing, i.e., associating signal strength with GPS location, and includes only signals that are above the system noise level.

f. The discrimination stage evaluated the demonstrator's ability to segregate ordnance from clutter. The same GPS locations reported in the response stage anomaly list were evaluated on the basis of the demonstrator's discrimination process (section 2.6). A discrimination stage list was generated and prioritized on the basis of the demonstrator's determination that an anomaly was more likely to be ordnance rather than clutter. Typically, higher output values indicate a higher confidence that an ordnance item is present at a specified location. The demonstrator then specifies the threshold value for the prioritized ranking that provides optimal system performance. This value is the discrimination stage threshold.

g. Both the response and discrimination lists contain the identical number of potential target locations, differing only in the priority ranking of the declarations.

h. Within both of these stages, the following entities were measured:

(1) P_d.

(2) Probability of false positive (P_{fp}).

(3) Probability of background alarm (P_{ba})/background alarm rate (BAR).

4.2.1 <u>ROC Curves</u>

a. Based on the entire range of ground truth targets used at this site, ROC curves were generated for both the response and discrimination stages. In both stages, the probability of detection versus false alarm rates was plotted. False alarms were divided into two groups: (1) anomalies corresponding to emplaced clutter items, thereby measuring the P_{fp}, and (2) anomalies not corresponding to any known item, termed background alarms (P_{ba}) in the blind grid area and BAR in all other areas.

b. The ROC curves for the response and discrimination stages for all areas surveyed are shown in Figures 9 through 12. Horizontal lines illustrate the system performance at the demonstrator's recommended noise level during the response stage, or discrimination threshold level in the discrimination stage. The point where the curve crosses the horizontal line defines the subset of targets the demonstrator recommends digging.

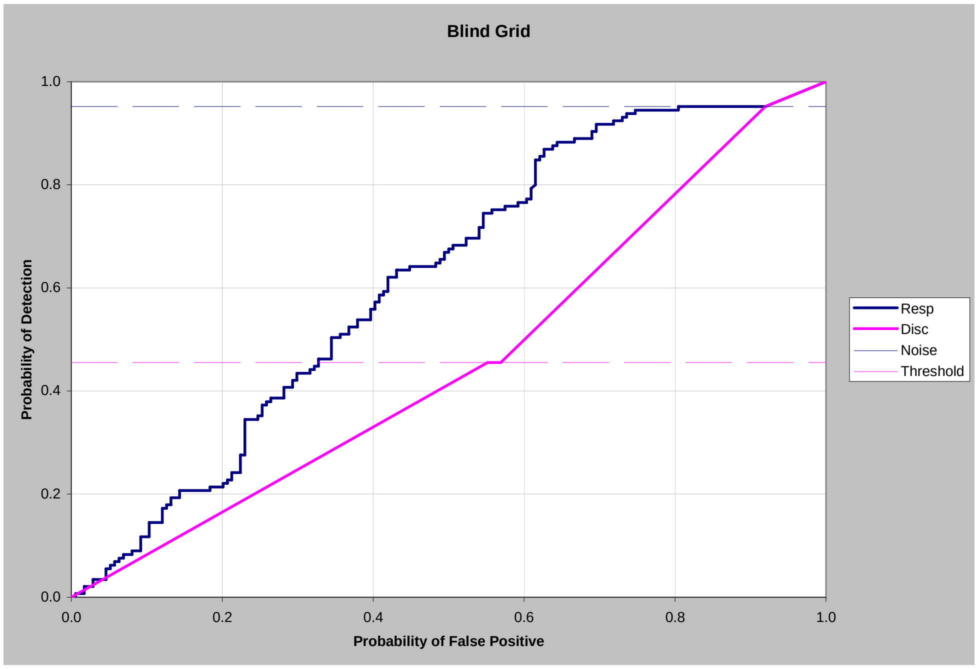

Figure 9. Blind grid P_d versus P_{fp}.

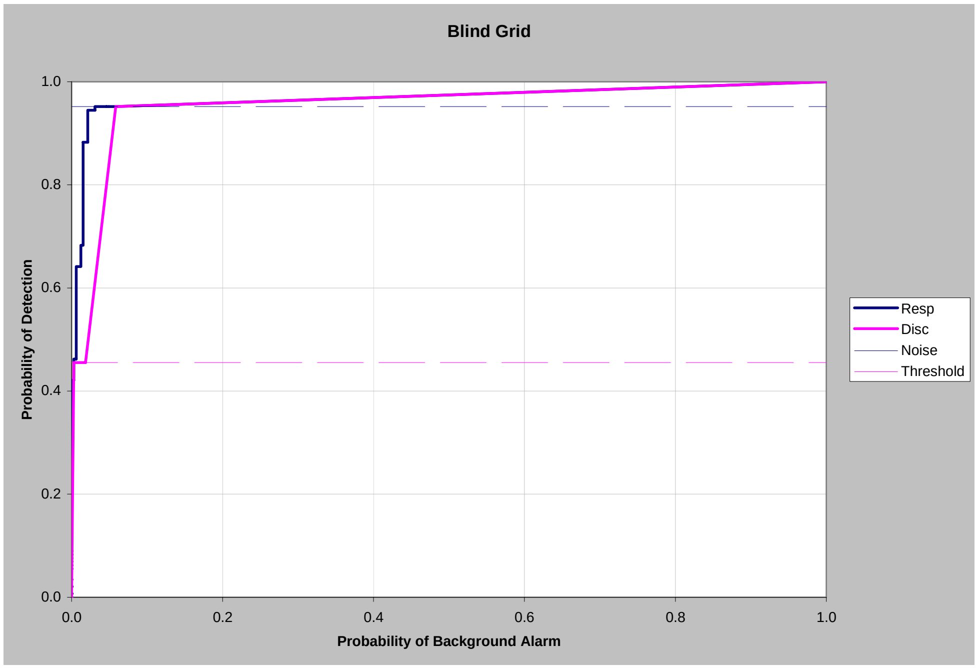

Figure 10. Blind grid P_d versus P_{ba}.

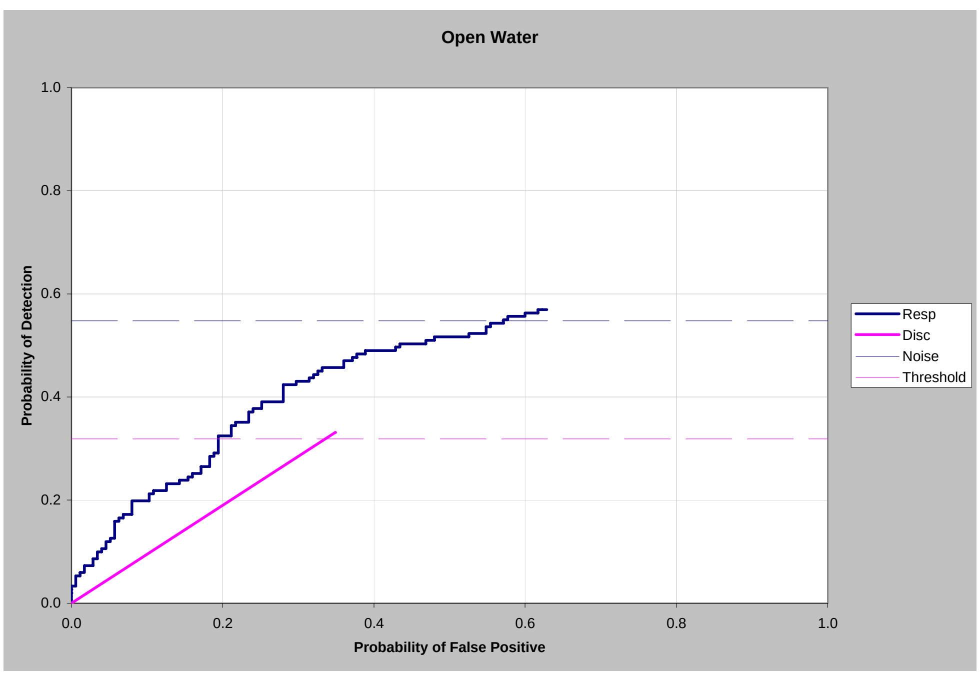

Figure 11. Open water P_d versus P_{fp}.

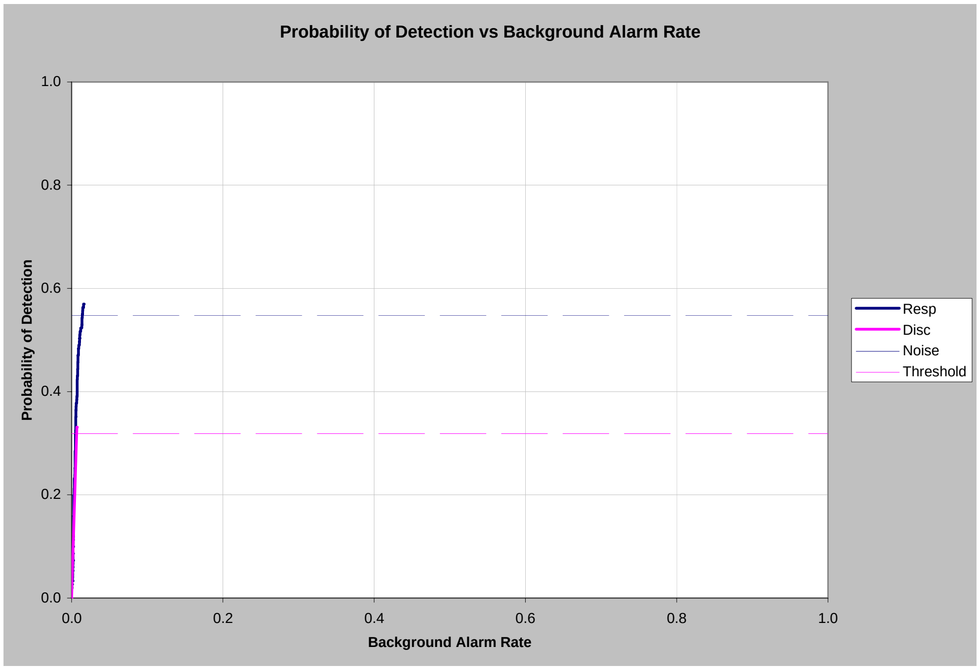

Figure 12. Open water P_d versus BAR.

4.2.2 Detection Results

Detection results, broken out by stage, area surveyed, and ordnance size, are presented in Table 4-2. The results by size indicate how well the demonstrator detected/discriminated ordnance of a given caliber. Overall results summarize ordnance detection over a given area. All values were calculated assuming the number of detections was a binomially distributed random variable. These results are reported at the 90 percent reliability/95 percent confidence levels unless otherwise noted.

TABLE 4-2. SYSTEM DETECTION SUMMARY

Metric	Overall	By Projectile Caliber					
		40 mm	60 mm	81 mm	105 mm	155 mm	8 in.
Blind grid							
Response stage							
P_d	95.2%	96.6%	93.1%	93.1%	100.0%	93.1%	
P_d lower 90% confidence	92.0%	87.2%	82.7%	82.7%	92.4%	82.7%	
P_{fp}	92.0%						
P_{fp} lower 90% confidence	88.6%						
P_{ba}	5.8%						
Discrimination stage							
P_d	45.5%	27.6%	44.8%	37.9%	55.2%	62.1%	
P_d lower 90% confidence	39.9%	16.8%	31.9%	25.7%	41.7%	48.5%	
P_{fp}	56.9%						
P_{fp} lower 90% confidence	51.8%						
P_{ba}	1.8%						
Open water							
Response stage							
P_d	54.8%	62.1%	51.7%	41.4%	62.1%	57.1%	50.0%
P_d lower 90% confidence	49.3%	48.5%	38.4%	28.8%	48.5%	44.9%	20.1%
P_{fp}	54.2%						
P_{fp} lower 90% confidence	49.4%						
BAR m^{-2}	0.016						
Discrimination stage							
P_d	31.8%	24.1%	24.1%	20.7%	55.2%	37.1%	16.7%
P_d lower 90% confidence	27.0%	14.0%	14.0%	11.2%	41.7%	26.1%	1.7%
P_{fp}	30.0%						
P_{fp} lower 90% confidence	25.8%						
BAR m^{-2}	0.007						
Littoral region							
Response stage							
P_d	Test area not surveyed						
P_d lower 90% confidence							
P_{fp}							
P_{fp} lower 90% confidence							
BAR m^{-2}							
Discrimination stage							
P_d	Test area not surveyed						
P_d lower 90% confidence							
P_{fp}							
P_{fp} lower 90% confidence							
BAR m^{-2}							
Deeper water							
Response stage							
P_d	24.1%					24.1%	
P_d lower 90% confidence	14.0%					14.0%	
Discrimination stage							
P_d	24.1%					24.1%	
P_d lower 90% confidence	14.0%					14.0%	
Response stage noise level: 0.55							
Recommended discrimination threshold: 1.5							

4.2.3 System Discrimination

Using the demonstrator's recommended setting, the items detected and correctly classified as ordnance were further evaluated as to whether the demonstrator could correctly identify the ordnance type. The list of ground truth ordnance items was provided to the demonstrator before testing.

NAEVA/XTECH's "dig list" discriminated between ordnance and clutter but not between ordnance types. The latter was an optional requirement.

4.2.4 System Effectiveness

Efficiency and rejection rates were calculated to quantify the discrimination ability at two specific points of interest on the ROC curve: the point where no decrease in P_d occurred (i.e., the efficiency is by definition equal to 1) and the operator-selected threshold. These values are presented in Table 4-3.

TABLE 4-3. EFFICIENCY AND REJECTION RATES

	Efficiency	**False Positive Rejection Rate**	**Background Alarm Rejection Rate**
Blind Grid			
At operating point	0.48	0.38	0.68
With no loss of P_d	1.00	0.38	0.68
Open Water			
At operating point	0.58	0.45	0.58
With no loss of P_d	1.00	0.45	0.58
Littoral Region			
At operating point	Test area not surveyed		
With no loss of P_d			

4.2.5 Chi-Square Analysis

A chi-square 2 × 2 Contingency Test for comparison between ratios was used to compare performance across test areas with regard to P_d^{res}, P_d^{disc}, P_{fp}^{res}, and P_{fp}^{disc}, efficiency, and false alarm rejection rates. The intent of the comparison was to determine whether the features introduced in each test region had a degrading effect on the performance of the sensor system.

This system did not survey enough of the other test areas to permit a valid comparison of performance between the areas.

4.2.6 Location Accuracy

The data points in the scatter graph shown in Figure 13 represent the coordinates of ordnance items in the open water test area that were first detected in the response stage within a 0.5-meter radius of their true positions and then correctly identified as ordnance in the discrimination stage. The maximum error represents the 0.5-meter detection limit. The mean error represents the statistical mean of the sample considered.

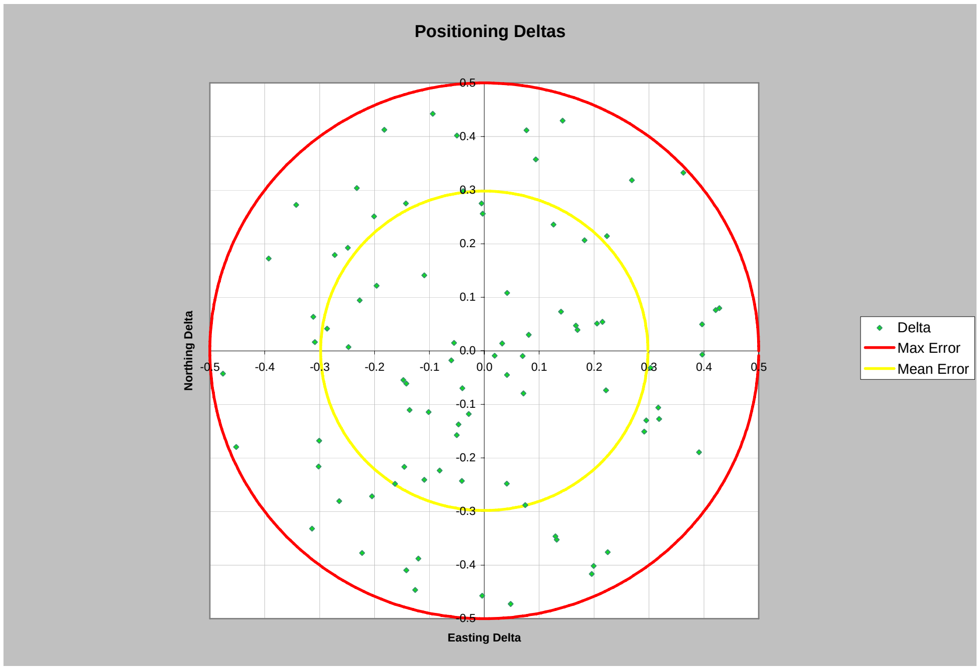

Figure 13. NAEVA/XTECH open water positioning deltas.

Comparisons made between the results obtained during testing and the EQT-ORD criteria are presented in Table 4-4.

TABLE 4-4. G882 TEST RESULTS - CRITERIA COMPARISON

<table>
<tr><th>Metric</th><th>Threshold</th><th>Objective</th><th colspan="2">By Area</th></tr>
<tr><td rowspan="3">Detection</td><td rowspan="3">80% ordnance items buried to 1 foot and under 8 feet (2.4 m) of water.</td><td rowspan="3">95% ordnance items buried to 4 feet and under 8 feet (2.4 m) of water.</td><td>Blind grid</td><td>95.2%</td></tr>
<tr><td>Open water</td><td>54.8%</td></tr>
<tr><td>Littoral</td><td>Not surveyed</td></tr>
<tr><td rowspan="4">Discrimination</td><td rowspan="3">Rejection rate of 50% of emplaced non-UXO clutter.</td><td rowspan="3">Rejection rate of 90% of emplaced non-UXO clutter.</td><td>Blind grid</td><td>38%</td></tr>
<tr><td>Open water</td><td>45%</td></tr>
<tr><td>Littoral</td><td>Not surveyed</td></tr>
<tr><td>Maximum false negative rate of 10%.</td><td>Maximum false negative rate of 0.5%.</td><td colspan="2">Not assessed. An analytical procedure is not available to address this criterion.</td></tr>
<tr><td>Reacquisition</td><td>Reacquire within 1 meter.</td><td>Reacquire within 0.5 meter.</td><td colspan="2">The number of correctly identified items is insufficient to draw any conclusions.</td></tr>
</table>

Note: The blind grid and open water areas are in general accordance with the threshold requirements.

SECTION 5. APPENDIXES

APPENDIX A. TEST CONDITIONS LOG

ATMOSPHERIC CONDITIONS

Date, 06	Time, EDT	Average Wind Direction, deg	Average Wind Speed, km/h	Wind Direction Average Standard Deviation, deg	Peak Wind Speed, km/h	Average Temperature, °C
3 Apr	0700	126	6.6	16	12.6	9.7
	0800	154	9.0	16	16.7	10.2
	0900	173	5.2	27	10.6	10.7
	1000	111	5.3	19	11.3	10.7
	1100	98	7.9	15	15.9	11.4
	1200	96	8.5	16	16.1	12.4
	1300	102	8.1	16	19.5	13.9
	1400	134	4.2	34	9.3	15.1
	1500	122	5.5	32	13.2	15.8
	1600	137	6.1	27	13.0	17.2
	1700	80	10.1	24	20.1	16.5
4 Apr	0700	292	17.9	11	30.6	7.8
	0800	297	22.7	13	39.1	7.9
	0900	297	26.9	12	47.2	7.8
	1000	304	27.0	15	46.4	8.2
	1100	313	25.1	16	43.1	9.0
	1200	301	23.3	16	40.9	10.1
	1300	297	24.5	18	45.2	11.3
	1400	283	24.6	16	50.1	11.9
	1500	286	28.2	14	46.9	12.5
	1600	294	28.2	16	51.0	12.8
	1700	287	26.1	17	44.9	13.0
5 Apr	0700	253	8.1	14	16.3	5.3
	0800	227	14.3	29	57.2	5.8
	0900	293	17.2	12	34.1	4.1
	1000	302	26.7	23	58.6	5.0
	1100	318	32.4	14	56.5	4.2
	1200	320	27.7	15	53.9	5.0
	1300	324	24.8	17	44.6	6.3
	1400	318	25.4	16	45.4	7.8
	1500	306	24.0	17	43.0	9.0
	1600	315	23.0	16	43.0	9.1
	1700	306	19.8	15	35.9	9.6
6 Apr	0700	261	8.1	8	13.7	6.3
	0800	262	8.5	10	15.0	6.4
	0900	275	10.3	12	18.5	7.4
	1000	315	10.1	17	17.4	8.6
	1100	336	13.7	19	25.3	9.3
	1200	335	13.4	18	25.3	10.3
	1300	320	13.2	18	23.7	11.6
	1400	312	12.6	21	26.6	12.9

Date, 06	Time, EDT	Average Wind Direction, deg	Average Wind Speed, km/h	Wind Direction Average Standard Deviation, deg	Peak Wind Speed, km/h	Average Temperature, ^{o}C
6 Apr	1500	313	12.7	19	26.2	14.2
	1600	308	11.4	21	23.3	14.9
	1700	312	7.9	41	17.2	15.6
7 Apr	0700	105	2.6	14	6.1	8.0
	0800	155	1.8	39	5.6	8.4
	0900	191	10.1	11	29.8	10.0
	1000	189	15.0	11	24.2	11.2
	1100	197	12.9	13	21.7	12.1
	1200	198	16.3	11	26.2	12.1
	1300	196	13.0	12	22.5	12.1
	1400	193	16.7	12	31.1	12.9
	1500	199	18.2	12	26.9	15.0
	1600	201	17.4	12	28.2	16.6
	1700	203	15.5	12	27.4	18.9
10 Apr	0700	20	6.1	10	10.5	2.7
	0800	43	2.6	22	8.4	5.6
	0900	2	6.1	23	14.0	7.6
	1000	21	9.3	26	18.8	9.9
	1100	356	9.0	28	17.2	11.6
	1200	333	8.4	25	14.3	12.9
	1300	184	6.4	68	16.1	14.5
	1400	172	8.2	37	18.4	14.8
	1500	195	14.5	15	21.1	14.7
	1600	190	12.9	15	19.8	15.1
	1700	174	8.9	23	17.7	15.9
11 Apr	0700	57	1.4	2	2.9	2.9
	0800	62	1.1	11	4.0	5.1
	0900	126	3.4	41	13.2	9.9
	1000	184	12.9	12	19.2	11.7
	1100	186	13.2	17	20.4	13.3
	1200	205	13.5	16	21.3	15.3
	1300	200	14.7	15	21.7	16.8
	1400	203	14.3	17	25.3	18.2
	1500	200	16.9	12	26.9	19.4
	1600	198	20.0	12	29.3	20.0
	1700	201	20.6	11	31.1	20.1
12 Apr	0700	138	4.2	9	7.2	8.1
	0800	144	5.2	15	10.3	9.6
	0900	187	10.6	15	19.3	11.9
	1000	196	19.2	14	30.8	14.2
	1100	188	20.0	12	29.5	15.4
	1200	193	20.3	11	30.8	17.3
	1300	189	18.7	12	29.3	19.3
	1400	180	18.7	12	30.4	20.0
	1500	173	19.6	11	34.9	19.8
	1600	180	19.5	12	32.2	20.1
	1700	177	17.5	13	31.2	20.0

Date, 06	Time, EDT	Average Wind Direction, deg	Average Wind Speed, km/h	Wind Direction Average Standard Deviation, deg	Peak Wind Speed, km/h	Average Temperature, °C
13 Apr	0700	194	6.6	35	17.1	13.8
	0800	208	6.3	18	11.6	13.7
	0900	222	7.9	15	13.4	14.6
	1000	233	8.1	25	15.0	16.2
	1100	236	9.2	19	14.2	18.4
	1200	263	11.6	52	24.6	20.7
	1300	299	13.8	17	23.7	22.0
	1400	283	13.4	19	24.6	23.4
	1500	299	12.6	20	26.7	24.6
	1600	314	13.7	19	34.5	24.8
	1700	311	15.0	18	29.0	24.9
14 Apr	0700	216	6.6	24	11.3	13.5
	0800	166	4.5	53	8.9	13.9
	0900	177	5.0	55	14.3	14.4
	1000	16	2.7	79	5.3	16.0
	1100	162	3.9	72	8.9	16.6
	1200	208	7.1	18	10.3	17.8
	1300	242	8.5	26	16.7	16.8
	1400	197	10.8	15	19.6	17.5
	1500	204	11.4	15	21.6	17.3
	1600	184	10.1	15	19.3	18.7
	1700	177	8.4	18	14.3	21.2

Note: The TIDALITE IV Portable Tide Gauge System© was not operational. Manual water depth and temperature measurements were recorded each morning. The single measurements for each day are shown in Table 3-1.

Company: NAEVA/XTECH **Date: 3 April 2006**			**Personnel: Leif Riddervold, Alexander Kostera, Vik Banerjee, Scott MacLellan**	
Start	**Stop**	**Remarks**	**Activity**	**Chargeable**
0830	0845	Arrived at site, light rain, ATC safety briefing	Downtime ATC	15
0845	0905	Walked around pond.	Initial setup	20
0905	1215	Setup.	Initial setup	190
1215	1245	Lunch.	Nonchargeable downtime	30
1245	1415	Setup. Rain limited the amount of setup that could be done.	Initial setup	90
1415	1440	Rain stopped setup.	Initial setup	25
	1440	Left site.		
1440	1600	Weather delay.	Weather delay	80

Company: NAEVA/XTECH **Date: 4 April 2006**			**Personnel: Leif Riddervold, Alexander Kostera, Vik Banerjee, Scott MacLellan**	
Start	**Stop**	**Remarks**	**Activity**	**Chargeable**
0830	1155	Arrived at site. Still initial setup. High winds created a small-craft advisory.	Initial setup	205
1155	1240	Sled in water calibrating (winds died down some).	Calibration	45
1240	1320	Replaced sections of rope used to pull the sled.	Downtime equipment	40
1320	1400	Survey attempt at collecting one or two lines. Stopped surveying because of high winds.	Data collection	40
1400	1410	Calibration.	Calibration	10
1410	1440	Cleanup.	Daily close-up	30
	1440	Left site.		
1440	1600	Weather delay.	Weather delay	80

Company: NAEVA/XTECH Date: 5 April 2006			**Personnel: Leif Riddervold, Alexander Kostera, Vik Banerjee, Scott MacLellan**	
Start	**Stop**	**Remarks**	**Activity**	**Chargeable**
0830	0920	Setup.	Daily setup	50
0920	0930	Static calibration.	Calibration	10
0930	0945	Canceled for the day because of current squall conditions and high winds. Cleanup.	Daily close-up	15
0945	1600	Weather delay.	Weather delay	345

Company: NAEVA/XTECH Date: 6 April 2006			**Personnel: Leif Riddervold, Alexander Kostera, Vik Banerjee, Scott MacLellan**	
Start	**Stop**	**Remarks**	**Activity**	**Chargeable**
0820	0915	Setup.	Daily setup	55
0915	0925	Survey.	Data collection	10
0925	1000	Poles that kept the towropes clear of the propeller were not deep enough in the water to accomplish their purpose. Lengthening the submerged poles solved the problem in the deeper water but created a "bottoming-out" problem in the shallower water.	Downtime equipment	35
1000	1025	Survey.	Data collection	25
1025	1045	Towropes again moved under the boat during turns. Problem resolved by attaching floats to the ropes.	Downtime equipment	20
1045	1115	Survey.	Data collection	30
1115	1120	Downloaded survey data.	Calibration	5
1120	1220	Lunch.	Nonchargeable downtime	60
1220	1330	Survey.	Data collection	70
1330	1340	Problem during a turn.	Downtime equipment	10
1340	1505	Survey.	Data collection	85
1505	1510	Static calibration.	Calibration	5
1510	1530	Sled maintenance: pulled sled from the water, checked zip ties and the physical condition of the coils.	Downtime equipment	20
1530	1630	Cleanup.	Daily close-up	60

Company: NAEVA/XTECH Date: 7 April 2006			Personnel: Leif Riddervold, Alexander Kostera, Vik Banerjee, Scott MacLellan	
Start	**Stop**	**Remarks**	**Activity**	**Chargeable**
0830	0935	Setup. A light rain was falling; winds were 6 to 10 mph with gusts to 16 mph. The rain was sufficient to cause concerns about the electronics in the open boat. Limited setup was done while the weather conditions were monitored.	Daily setup	65
0935	0935	The decision was made to cancel because of the weather rather then risk damage to the equipment.		
0935	0950	Secured boat for the weekend.	Daily close-up	15
0950	1600	Weather delay.	Weather delay	340

Company: NAEVA/XTECH Date: 10 April 2006			Personnel: Leif Riddervold, Alexander Kostera, Vik Banerjee, Scott MacLellan	
Start	**Stop**	**Remarks**	**Activity**	**Chargeable**
0810	0905	Setup; bailed boat from weekend rain.	Daily setup	55
0905	0910	Static calibration.	Calibration	5
0910	1010	Survey.	Data collection	60
1010	1015	Platform tipped onto its side far enough to submerge the GPS antenna. System appeared okay.	Downtime equipment	5
1015	1050	Survey.	Data collection	35
1050	1055	Platform tipped again; antenna did not submerge.	Downtime equipment	5
1055	1115	Survey.	Data collection	20
1115	1210	Outboard motor problems: one cylinder's plug was fouling at the low speeds needed to pull the sled. Mechanic called.	Downtime equipment	55
1210	1240	Lunch.	Nonchargeable downtime	30
1240	1255	Changed spark plug.	Downtime equipment	15
1255	1415	Survey.	Data collection	20
1415	1445	Battery on charge for 30 minutes.	Downtime equipment	30
1445	1550	Survey.	Data collection	65
1550	1600	Sled appeared to have too much drag; returned to dock and pulled sled from the water. Everything looked all right.	Downtime equipment	10
1600	1700	Survey.	Data collection	60
1700	1715	Noise in both coil channels. Removed sled from water to allow the connections to dry overnight.	Downtime equipment	15
1715	1730	Cleanup.	Daily close-up	15
	1730	Left site.		

Company: NAEVA/XTECH Date: 11 April 2006			Personnel: Leif Riddervold, Alexander Kostera, Vik Banerjee, Scott MacLellan	
Start	**Stop**	**Remarks**	**Activity**	**Chargeable**
0755	0845	Setup.	Daily setup	50
0845	0855	Static calibration.	Calibration	10
0855	0905	Survey.	Data collection	10
0905	0915	Problems with towropes.	Downtime equipment	10
0915	0920	Survey.	Data collection	5
0920	0930	Changed plug in outboard motor.	Downtime equipment	10
0930	1010	Survey.	Data collection	40
1010	1020	Nonsurvey, conference on water.	Downtime	10
1020	1200	Survey.	Data collection	100
1200	1300	Lunch; recharged battery.	Nonchargeable downtime	60
1300	1320	Loaded survey files.	Calibration	20
1320	1605	Survey.	Data collection	165
1605	1625	Static calibration.	Calibration	20
1630	1640	Downloaded survey files.	Calibration	10
1640	1700	Cleanup.	Daily close-up	20

Company: NAEVA/XTECH Date: 12 April 2006			Personnel: Leif Riddervold, Alexander Kostera, Vik Banerjee, Scott MacLellan	
Start	**Stop**	**Remarks**	**Activity**	**Chargeable**
0805	0825	Setup.	Daily setup	35
0825	0900	Attempted positioning of the sled using personnel on the shore to survey the littoral area.	Daily setup	35
0900	1300	Troubleshooting noise in coils.	Downtime equipment	240
1300	1305	Static check.	Calibration	5
1305	1515	Survey.	Data collection	130
1515	1530	Lunch.	Non-chargeable downtime	15
1530	1620	Survey.	Data collection	50
1620	1650	Cleanup.	Daily close-up	30

Company: NAEVA/XTECH **Date: 13 April 2006**			**Personnel: Leif Riddervold, Vik Banerjee, Scott MacLellan**	
Start	**Stop**	**Remarks**	**Activity**	**Chargeable**
0755	1000	Troubleshooting coils; decided to work with current noise levels.	Downtime equipment	125
1000	1110	Extended the length of the 12.5-foot mast by 3 feet to allow operation in deeper water.	Downtime equipment	70
1110	1115	Static calibration.	Calibration	5
1115	1445	Survey.	Data collection	210
1445	1500	Refueled boat.	Downtime equipment	15
1500	1605	Survey.	Data collection	65
1605	1625	Cleanup, data dump.	Daily close-up	20

Company: NAEVA/XTECH **Date: 14 April 2006**			**Personnel: Leif Riddervold, Vik Banerjee, Scott MacLellan**	
Start	**Stop**	**Remarks**	**Activity**	**Chargeable**
0810	0840	Setup.	Daily setup	30
0840	0850	Static calibration.	Calibration	10
0850	1130	Survey.	Data collection	155
1130	1135	Static calibration.	Calibration	5
1135	1430	Packed up.	Demobilization	175

APPENDIX C. TERMS AND DEFINITIONS

GENERAL DEFINITIONS

Anomaly: Location of a system response deemed to warrant further investigation by the demonstrator for consideration as an emplaced ordnance item.

Detection: An anomaly location that is within R_{halo} of an emplaced ordnance item.

Munitions and Explosives of Concern (MEC): Specific categories of military munitions that may pose unique explosive safety risks, including UXO as defined in 10 USC 101(e)(5), DMM as defined in 10 USC 2710(e)(2) and/or munitions constituents (e.g., TNT, RDX) as defined in 10 USC 2710(e)(3) that are present in high enough concentrations to pose an explosive hazard.

Emplaced Ordnance: An ordnance item buried by the government at a specified location in the test site.

Emplaced Clutter: A clutter item (i.e., nonordnance item) buried by the government at a specified location in the test site.

R_{halo}: A predetermined radius about the periphery of an emplaced item (clutter or ordnance) within which a location identified by the demonstrator as being of interest is considered to be a response from that item. For the purpose of this program, a circular halo 0.5 meters in radius will be placed around the center of the object for all clutter and ordnance items less than 0.6 meters in length. When ordnance items are longer than 0.6 meters, the halo becomes an ellipse where the minor axis remains 1 meter and the major axis is equal to the projected length of the ordnance onto the ground plane plus 1 meter.

Response Stage Noise Level: The level that represents the point below which anomalies are not considered detectable. Demonstrators are required to provide the recommended noise level for the blind grid test area.

Discrimination Stage Threshold: Demonstrator's select the threshold level that they believe provides optimum performance of the system by retaining all detectable ordnance and rejecting the maximum amount of clutter. This level defines the subset of anomalies the demonstrator would recommend digging based on discrimination.

Binomially Distributed Random Variable: A random variable of the type that has only two possible outcomes, say success and failure, and is repeated for n independent trials with the probability p of success and the probability 1-p of failure being the same for each trial. The number of successes x observed in the n trials is an estimate of p and is considered to be a binomially distributed random variable.

RESPONSE STAGE DEFINITIONS

Response Stage Probability of Detection (P_d^{res}): P_d^{res} = (No. of response stage detections)/(No. of emplaced ordnance in the test site).

Response Stage False Positive (fp^{res}): An anomaly location that is within R_{halo} of an emplaced clutter item.

Response Stage Probability of False Positive (P_{fp}^{res}): P_{fp}^{res} = (No. of response stage false positives)/(No. of emplaced clutter items).

Response Stage Background Alarm: An anomaly in a blind grid cell that contains neither emplaced ordnance nor an emplaced clutter item. An anomaly location in the open water or littoral scenarios that is outside R_{halo} of any emplaced ordnance or emplaced clutter item.

Response Stage Probability of Background Alarm (P_{ba}^{res}): blind grid only: P_{ba}^{res} = (No. of response stage background alarms)/(No. of empty grid locations).

Response Stage Background Alarm Rate (BAR^{res}): open water only: BAR^{res} = (No. of response stage background alarms)/(arbitrary constant).

Note that the quantities P_d^{res}, P_{fp}^{res}, P_{ba}^{res}, and BAR^{res} are functions of t^{res}, the threshold applied to the response stage signal strength. These quantities can, therefore, be written as $P_d^{res}(t^{res})$, $P_{fp}^{res}(t^{res})$, $P_{ba}^{res}(t^{res})$, and $BAR^{res}(t^{res})$.

DISCRIMINATION STAGE DEFINITIONS

Discrimination: The application of a signal processing algorithm or human judgment to response stage data that discriminates ordnance from clutter. Discrimination should identify anomalies that the demonstrator has high confidence correspond to ordnance, as well as those that the demonstrator has high confidence correspond to nonordnance or background returns. The former should be ranked with highest priority and the latter with lowest.

Discrimination Stage Probability of Detection (P_d^{disc}): P_d^{disc} = (No. of discrimination stage detections)/(No. of emplaced ordnance in the test site).

Discrimination Stage False Positive (fp^{disc}): An anomaly location that is within R_{halo} of an emplaced clutter item.

Discrimination Stage Probability of False Positive (P_{fp}^{disc}): P_{fp}^{disc} = (No. of discrimination stage false positives)/(No. of emplaced clutter items).

Discrimination Stage Background Alarm: An anomaly in a blind grid cell that contains neither emplaced ordnance nor an emplaced clutter item. An anomaly location in the open water or littoral scenarios that is outside R_{halo} of any emplaced ordnance or emplaced clutter item.

Discrimination Stage Probability of Background Alarm (P_{ba}^{disc}): P_{ba}^{disc} = (No. of discrimination stage background alarms)/(No. of empty grid locations).

Discrimination Stage Background Alarm Rate (BAR^{disc}): BAR^{disc} = (No. of discrimination stage background alarms)/(arbitrary constant).

Note that the quantities P_d^{disc}, P_{fp}^{disc}, P_{ba}^{disc}, and BAR^{disc} are functions of t^{disc}, the threshold applied to the discrimination stage signal strength. These quantities can, therefore, be written as $P_d^{disc}(t^{disc})$, $P_{fp}^{disc}(t^{disc})$, $P_{ba}^{disc}(t^{disc})$, and $BAR^{disc}(t^{disc})$.

RECEIVER OPERATING CHARACERISTIC (ROC) CURVES

ROC curves at both the response and discrimination stages can be constructed on the basis of the above definitions. The ROC curves plot the relationship between P_d versus P_{fp} and P_d versus BAR or P_{ba} as the threshold applied to the signal strength is varied from its minimum (t_{min}) to its maximum (t_{max}) value.[1] Figure A-1 shows how P_d versus P_{fp} and P_d versus BAR are combined into ROC curves. Note that the "res" and "disc" superscripts have been suppressed from all the variables for clarity.

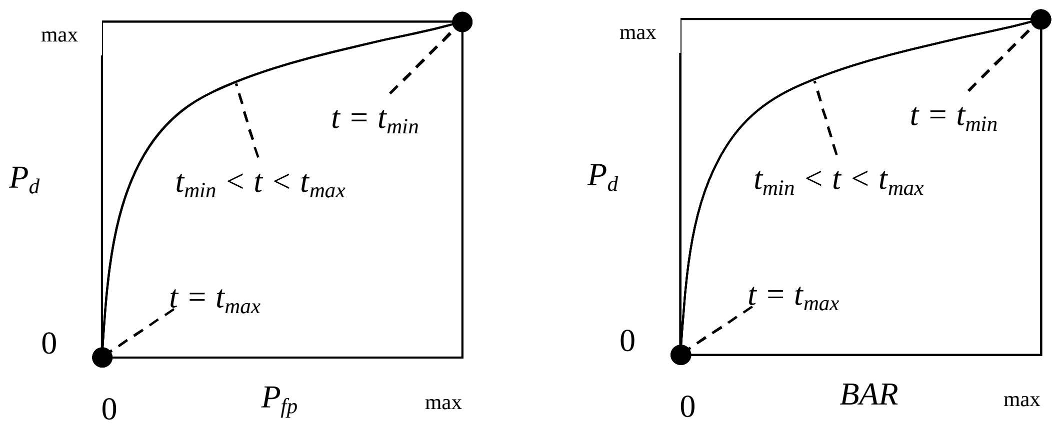

Figure A-1. ROC curves for open-site testing. Each curve applies to both the response and discrimination stages.

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[1]Strictly speaking, ROC curves plot the P_d versus P_{ba} over a predetermined and fixed number of detection opportunities (some of the opportunities are located over ordnance and others are located over clutter or blank spots). In an open water scenario, each system suppresses its signal strength reports until some bare-minimum signal response is received by the system. Consequently, the open water ROC curves do not have information from low-signal output locations, and, furthermore, different contractors report their signals over a different set of locations on the ground. These ROC curves are thus not true to the strict definition of ROC curves as defined in textbooks on detection theory. Note, however, that the ROC curves obtained in the blind grid test sites are true ROC curves.

METRICS TO CHARACTERIZE THE DISCRIMINATION STAGE

The demonstrator is also scored on efficiency and rejection ratio, which measure the effectiveness of the discrimination stage processing. The goal of discrimination is to retain the greatest number of ordnance detections from the anomaly list while rejecting the maximum number of anomalies arising from non ordnance items. The efficiency measures the amount of detected ordnance retained by the discrimination, while the rejection ratio measures the fraction of false alarms rejected. Both measures are defined relative to the entire response list, i.e., the maximum ordnance detectable by the sensor and its accompanying false positive rate or background alarm rate.

Efficiency (E): $E = P_d^{disc}(t^{disc})/P_d^{res}(t_{min}^{res})$: measures (at a threshold of interest), the degree to which the maximum theoretical detection performance of the sensor system (as determined by the response stage t_{min}) is preserved after application of discrimination techniques. Efficiency is a number between 0 and 1. An efficiency of 1 implies that all of the ordnance initially detected in the response stage was retained at the specified threshold in the discrimination stage, t^{disc}.

False Positive Rejection Rate (R_{fp}): $R_{fp} = 1 - [P_{fp}^{disc}(t^{disc})/P_{fp}^{res}(t_{min}^{res})]$: measures (at a threshold of interest), the degree to which the sensor system's false positive performance is improved over the maximum false positive performance (as determined by the response stage t_{min}). The rejection rate is a number between 0 and 1. A rejection rate of 1 implies that all emplaced clutter initially detected in the response stage was correctly rejected at the specified threshold in the discrimination stage.

Background Alarm Rejection Rate (R_{ba}):

Blind Grid: $R_{ba} = 1 - [P_{ba}^{disc}(t^{disc})/P_{ba}^{res}(t_{min}^{res})]$
Open Water: $R_{ba} = 1 - [BAR^{disc}(t^{disc})/BAR^{res}(t_{min}^{res})])$

Measures the degree to which the discrimination stage correctly rejects background alarms initially detected in the response stage. The rejection rate is a number between 0 and 1. A rejection rate of 1 implies that all background alarms initially detected in the response stage were rejected at the specified threshold in the discrimination stage.

CHI-SQUARE COMPARISON EXPLANATION

The chi-square test for differences in probabilities (or 2 x 2 contingency table) is used to analyze two samples drawn from two different populations to see if both populations have the same or different proportions of elements in a certain category. More specifically, two random samples are drawn, one from each population, to test the null hypothesis that the probability of event A (some specified event) is the same for both populations (ref 3, pages 144 through 151).

A one-sided 2 x 2 contingency table is used in the Shallow Water Site Program to compare each area (open water, littoral, deep water) to the blind grid since each area introduces a water feature that makes it potentially more difficult to survey than the blind grid. The one-sided 2 x 2 contingency table is used to determine if there is reason to believe that the

proportion of ordnance correctly detected/discriminated by demonstrator X's system is significantly degraded by the more challenging feature introduced. A two-sided 2 x 2 contingency table is used to compare performance between any two of the test sites other than the blind grid to determine if there is reason to believe that the proportion of ordnance correctly detected/discriminated by demonstrator X's system is significantly different between those two test sites.

The test statistic of the 2 x 2 contingency table is the chi-square distribution with one degree of freedom. For the one-sided test, a significance level of 0.05 is chosen, which sets a critical decision limit of 3.84 from the chi-square distribution with one degree of freedom. It is a critical decision limit because if the test statistic calculated from the data exceeds this value, the two proportions tested will be considered significantly different. If the test statistic calculated from the data is less than this value, the two proportions tested will be considered not significantly different.

An exception must be applied when either a 0 or 100 percent success rate occurs in the sample data. The chi-square test cannot be used in these instances. Instead, Fisher's Exact Test is used, and the critical decision limit is the chosen significance level, which is 0.05 for one-sided tests and 0.10 for two-sided tests. With Fisher's test, if the test statistic (p-value) is less than the critical value, then the null hypothesis of similar performance is rejected in favor of the alternative hypothesis: significantly greater than for the one-sided case or significantly different for the two-sided case.

Shallow Water UXO Detection Test Site examples, where blind grid results are compared to those from the open water and littoral sites and the nongrid sites (open water and littoral), are compared to each other as follows. It should be noted that a significant result does not prove a cause and effect relationship exists between the change in survey area and sensor performance; however, it does serve as a tool to indicate that one data set reflects relatively degraded system performance of a large enough scale than can be accounted for merely by chance or random variation. Note also that a result that is not significant indicates that there is not enough evidence to declare that anything more than chance or random variation within the same population is at work between the two data sets being compared.

Demonstrator X achieves the following overall results after surveying each of the three areas using the same system (results indicate the number of ordnance detected divided by the number of ordnance emplaced):

	Blind grid	Open water	Littoral
P_d^{res}	100/100 = 1.0	8/10 = .80	20/33 = .61
P_d^{disc}	80/100 = 0.80	6/10 = .60	8/33 = .24

P_d^{res}: BLIND GRID versus OPEN WATER. Using the example data above to compare probabilities of detection in the response stage, all 100 ordnance out of 100 emplaced ordnance items were detected in the blind grid while 8 ordnance out of 10 emplaced were detected in the open water. Fisher's test must be used since a 100 percent success rate occurs in the data. Fisher's test uses the four input values to calculate a test statistic (p-value) of 0.0075 that is

compared against the critical value of 0.05. Since the test statistic is less than the critical value, the smaller response stage detection rate (0.80) is considered to be significantly less at the 0.05 level of significance. While a significant result does not prove a cause and effect relationship exists between the change in survey area and degradation in performance, it does indicate that the detection ability of demonstrator X's system seems to have been degraded in the open water relative to results from the blind grid using the same system.

P_d^{disc}: BLIND GRID versus OPEN WATER. Using the example data above to compare probabilities of detection in the discrimination stage, 80 out of 100 emplaced ordnance items were correctly discriminated as ordnance in blind grid testing while 6 out of 10 emplaced ordnance items were correctly discriminated as such in open water testing. Those four values are used in the chi-square Contingency Test to calculate a test statistic of 1.12. Since the test statistic is less than the critical value of 3.84, the two discrimination stage detection rates are considered to be not significantly different at the 0.05 level of significance.

P_d^{res}: BLIND GRID versus LITTORAL. Using the example data above to compare probabilities of detection in the response stage, 100 out of 100 and 20 out of 33 are used to calculate a test statistic (< 0.000) that is compared against the critical value of 0.05. Since the test statistic is less than the critical value, the smaller response stage detection rate (0.61) is considered to be significantly less at the 0.05 level of significance.

P_d^{disc}: BLIND GRID versus LITTORAL. Using the example data above to compare probabilities of detection in the discrimination stage, 80 out of 100 and 8 out of 33 emplaced ordnance items were correctly discriminated as such in open water testing. Those four values are used to calculate a test statistic of 32.01. Since the test statistic is greater than the critical value of 3.84, the smaller discrimination stage detection rate (0.24) is considered to be significantly less at the 0.05 level of significance.

P_d^{res}: OPEN WATER versus LITTORAL. Using the example data above to compare probabilities of detection in the response stage, 8 out of 10 and 20 out of 33 are used to calculate a test statistic of 0.56. Since the test statistic is less than the critical value of 2.71, the two response stage detection rates are considered to be not significantly different at the 0.10 level of significance.

P_d^{disc}: OPEN WATER versus LITTORAL. Using the example data above to compare probabilities of detection in the discrimination stage, 6 out of 10 and 8 out of 33 are used to calculate a test statistic of 2.98. Since the test statistic is greater than the critical value of 2.71, the two discrimination stage detection rates are considered to be significantly different at the 0.10 level of significance. While a significant result does not prove a cause and effect relationship exists between the change in survey area and change in performance, it does indicate that the ability of Demonstrator X to correctly discriminate seems to have been degraded by features of the littoral area relative to results from the open water using the same system.

APPENDIX D. REFERENCES

1. Environmental Quality Technology - Operational Requirements Document (EQT-ORD) for: A(1.6.a): UXO Screening, Detection and Discrimination.

2. Proposal for Shallow Water Unexploded Ordnance (UXO) Detection & Discrimination Technology Demonstration Volume 1 - Technical/Management (Plan). Submitted in response to BAA W91ZLK-04-R-0001, by NAEVA Geophysics, Inc., 30 August 2005.

3. Practical Nonparametric Statistics, W.J. Conover, John Wiley & Sons, 1980, pages 144 through 151.

APPENDIX E. ABBREVIATIONS

ABS	=	acrylonitrile-butadiene-styrene
ADST	=	Aberdeen Data Services Team
APG	=	Aberdeen Proving Ground
ATC	=	U.S. Army Aberdeen Test Center
BAA	=	Broad Agency Announcement
BAR	=	background alarm rate
DMM	=	discarded military munitions
EM	=	electromagnetic
EQT	=	Army Environmental Quality Technology Program
EQT-ORD	=	Environmental Quality Technology - Operational Requirements Document
ERDC	=	U.S. Army Corps of Engineers Engineering, Research and Development Center
ESTCP	=	Environmental Security Technology Certification Program
GPS	=	Global Positioning System
LED	=	light-emitting diode
MEC	=	munitions and explosives of concern
METDC	=	Military Environmental Technology Demonstration Center
P_{ba}	=	probability of background alarm rate
P_d	=	probability of detection
P_d^{disc}	=	probability of detection, discrimination stage
P_d^{res}	=	probability of detection, response stage
P_{fp}	=	probability of false positive
P_{fp}^{disc}	=	probability of false positive, discrimination stage
P_{fp}^{res}	=	probability of false positive, response stage
POC	=	point of contact
QA	=	quality assurance
QC	=	quality control
ROC	=	receiver operating characteristic
SERDP	=	Strategic Environmental Research and Development Program
USAEC	=	U.S. Army Environmental Command
UXO	=	unexploded ordnance

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